NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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NACA APPARATUS AND METHODS FOR TAKE-OFF AND LANDING MEASUREMENTS

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INTRODUCTION

Experience has shown that the determination of the take-off and landing characteristics of airplanes requires specialized equipment of a high degree of precision and reliability and demands great care in the evaluation and interpretation of data. It is believed, therefore, that a description of the apparatus and methods that have been developed by the NACA for these measurements might be of considerable interest, particularly to flight-test groups that have had little experience with landing and take-off measurements.

The basic principles and essential details of the Committee's equipment are described, the methods of utilizing the apparatus and of reducing the data are explained, and sample test results are presented.

REQUIREMENTS OF TAKE-OFF AND LANDING MEASUREMENTS

In general, the ultimate purpose of take-off or landing measurements is to determine the horizontal distance that an airplane traverses during take-off or landing. This distance, however, whether it includes the distance required to ascend (or descend) through a given height range, in addition to the distance rolled on the ground or only the ground-run distance, is critically affected by variations in piloting technique and wind conditions. The distance measured from an individual test, however accurate, is therefore not significant unless sufficient supplementary information is obtained to define completely the conditions of the test. Thus, it is practically essential that the measurements be of such a nature as to permit an accurate determination of the speed

of the airplane relative to the ground and also relative to the air. In addition, determinations of the longitudinal attitude angle of the airplane, acceleration components, and vertical velocity are often required.

The NACA apparatus and testing technique was designed to fulfill, as nearly as possible, the foregoing requirements.

NACA APPARATUS FOR TAKE-OFF AND LANDING MEASUREMENTS

The basic item of equipment is an especially designed combination of motion-picture camera and recording theodolite, which is designated the NACA phototheodolite. (See fig. 1.) The camera is equipped with a telephoto lens of approximately 15 inches focal length, having an aperture adjustment from f4.5 to f32. The shutter is of the rotating disc type with a segment aperture adjustable to give exposure times of 1/9, 2/9, or 4/9 of the interval between exposures. A small electric motor, supplemented by the inertia of a flywheel, actuates the shutter and film advance mechanism at any desired speed up to 32 exposures per second; the camera speed is indicated by a tachometer. Standard 35-millimeter motion-picture film is used; panchromatic film with an emulsion speed of 64 Weston has been found satisfactory for normal lighting conditions. The film is wound in detachable magazines having a capacity of 100 feet. A telescopic sight mounted on the top of the camera case is used as a view finder.

A trunnion-type mounting, which rides on a horizontal bronze bearing plate, provides for rotation of the camera in elevation and azimuth. The bearing plate is supported by four leveling screws in an arrangement similar to that used for transits and theodolites. Two small spirit levels are mounted at right angles to one another on the base of the instrument to provide for approximate leveling; a large, extra-sensitive level is fixed to the top of the camera case for final leveling of the base and to permit accurate leveling of the camera itself.

Orientation of the phototheodolite is effected in azimuth by means of an annular dial affixed to the horizontal bearing plate and in elevation by means of a cylindrical dial concentric with the elevation axis and

fixed with respect to the camera. The elevation dial is tangent to the plane of the azimuth dial, and vernier scales, approximately parallel and immediately adjacent to one another, are interposed between the two dials as shown in figure 2. The dials are marked with divisions of 0.5° and the vernier scales are graduated in intervals of 2 minutes of arc. The verniers and adjacent sections of the dials, all enclosed within the casing of the instrument base, are illuminated by automobile-headlight lamps and their image is brought to focus at the film by a system of lenses and prisms. One of the prisms is arranged to rotate about the elevation axis at one-half the speed of rotation of the camera about this axis. This arrangement allows for the angular displacement of the camera relative to the verniers.

Correlation of the phototheodolite records with time is accomplished with a counter actuated at uniform time intervals by circuit interruptions effected by an electrical timer. The counter reading, the angular displacement readings, and the airplane are photographed simultaneously on the same film frame. (See fig. 3.) An approximately square section of the frame, about 0.65 inch on a side, is available for the photograph of the airplane so that the field of view of the camera is about 2.5°, both horizontally and vertically.

Three 6-volt wet-cell batteries furnish the power required to operate the phototheodolite and timer.

The phototheodolite is mounted on a bowl-head tripod of a standard commercial type but, owing to the rather considerable weight of the instrument, the points of the tripod legs do not provide adequate footing on any but paved or similarly hard surfaces. For softer surfaces, such as turf, the point in each leg of the tripod is set in a small, firmly anchored, steel plate to ensure that the instrument will remain accurately leveled throughout the course of the tests.

Inasmuch as it is generally required to obtain supplementary data with recording instruments in the airplane, particularly with an airspeed recorder and timer and very often with an accelerometer, it is necessary to provide some means of sychronizing the records of these instruments with the phototheodolite records. This correlation is accomplished with a long duration photographic

flash bulb located in such a position on the airplane that the flash may be recorded by the phototheodolite. (See fig. 3.) Throwing the switch to ignite the flash bulb causes a simultaneous, distinctive marking on the record of one of the instruments in the airplane. Two bulbs ignited at different times to allow for the possibility of obscuration or failure of one of them are normally used for each landing or take-off run. It has been found that the flash of a single bulb can be recorded satisfactorily at a distance of at least a mile.

In order to permit an adequate correction of test results for wind conditions, it is desirable to obtain a continuous determination of the wind speed encountered by the airplane during the test run. The most suitable method appears to be that of accurately determining the speed of the airplane relative to the ground and relative to the air and taking the difference between the two at any instant as the wind speed. The speed with respect to the ground can be determined from the phototheodolite data. The correct airspeed can be obtained with an airspeed recorder by utilizing the principles outlined in reference 1. In the event that the foregoing method is not practicable, the wind speed can be measured by means of an anemometer, but such a device, although it may measure accurately the wind speed in its immediate vicinity, may give only a rough indication of the wind speed actually encountered by the airplane, particularly during the air-borne stage of a take-off or landing.

TEST PROCEDURE

Two systems of landing and take-off measurements utilizing the phototheodolites have been employed by the NACA. For the first system a single phototheodolite is set up to one side of the preselected take-off or landing course at such a distance from the course that the image of the airplane in the photographs will be reasonably large and yet will not entail an excessive angular traverse of the instrument in following the airplane through its run. (A distance of 1500 to 2000 ft has usually been found satisfactory where the over-all run does not exceed about 2000 ft.) The position of the phototheodolite station along the course is selected so that the instrument will be directed normal to the course approximately midway of the expected run. With this system, the direction of

the airplane's course relative to the azimuth scale of the phototheodolite is usually determined for each run by identifying the photograph in which the longitudinal axis of the airplane appears normal to the optic axis of the camera. The length of the airplane image in this frame, the corresponding azimuth angle reading, the actual length of the airplane, and the focal length of the camera lens constitute all the information required to permit evaluation of the records, provided that there is reasonable assurance that the airplane's course is straight and that it is not yawed with respect to its course. These conditions are ordinarily satisfied for the case where the airplane is in contact with the ground. It has been observed, however, that when the airplane is air-borne its course may depart considerably from a straight line and it may be materially yawed, in which cases the course cannot be adequately defined by means of the phototheodolite records alone. Auxiliary means such as dropping small sacks of lime from the airplane at intervals during the run, have in some cases been employed to delineate the course. Such a procedure, however, involves tapeline or chain measurements and, in many instances, is not practicable.

The second system requires the use of two phototheodolites but is generally more reliable and flexible than the single-instrument method. In this system the phototheodolites are set up on a base line roughly parallel to the expected course and at a distance from it determined from considerations of the image size desired in the photographs and the rate of change of azimuth angle that will be required of the phototheodolites in following the airplane (too high a rate of traverse causes difficulty in keeping the airplane within the field of view of the camera). The positions of the phototheodolites along the course are selected to have the two perpendiculars to the course from the phototheodolites subtend approximately that portion of the take-off or landing run for which the greatest possible accuracy is required for velocity determination. Both instruments are trained on the airplane throughout its run and the records of the two are correlated with one another and with the records of the instruments in the airplane by the flash-bulb method previously described.

The distance between the two phototheodolites is determined by direct measurement with tapeline or chain and the direction of the base line relative to the azimuth-angle scales of the two instruments is determined by

sighting and photographing each phototheodolite with the other.

It has been found very desirable, in general, to conduct landing and take-off tests when the wind is steady and of relatively low velocity, that is, less than 10 miles per hour, in order to avoid excessive wind corrections and the indeterminate effects of turbulent air. Furthermore, since it is not always possible to use a runway exactly parallel to the wind direction, higher wind velocities may introduce considerable cross-wind components during the landing or take-off.

Prior to the actual landing or take-off tests the airplane is weighed and the center of gravity located, the airspeed installation is usually calibrated for position errors, and the power-off stalling speeds and, for take-off, the power-on stalling speeds at as nearly full power as possible, are determined. The take-off or landing airspeed and the airspeed at a specified height in the initial climb or final approach, suitable to the particular airplane or airplane condition, are prescribed from a consideration of the stalling speed and the control and stability characteristics. The pilot is requested to effect the landings or take-offs as nearly as possible at these speeds.

An alternative procedure for take-off measurements to that of measuring both the ground-run and air-run distances directly may be employed in certain circumstances or for certain applications. This method consists of measuring the ground-run distance directly, as before, the airplane being held on the ground until the speed is in excess of any likely to be of interest. One or two tests will ordinarily be sufficient to establish the relationship between ground-run distance and speed for a particular airplane condition. The air-run distance is then calculated from the results of saw-tooth climb tests and added to the measured ground-run distance. Such a procedure might be followed, for example, in order to determine the take-off distance that would be required for a multiengine airplane in the event of engine failure during take-off, where actual tests close to the ground under the desired conditions would be unduly hazardous. The distance determined by this method will require estimation or neglect of the transition distance, that is, of the distances required to effect the change in flight-path direction from horizontal to climbing, and will not include

the ground effect on the air run. For an airplane with a high power loading, either normally or such as might be occasioned by failure of part of the engines, the transition distance may be relatively small and will be at least partly compensated for by neglect of the ground effect.

During take-off or landing tests the pilot is requested to note engine operating conditions (engine speed, manifold pressure, carburetor-air temperature, mixture-control setting, torque if available, etc.), wing and cowl flap settings, and any other pertinent information that may be available to him, in order that the test data can be properly interpreted and corrected. Barometric pressure and air temperature are noted by the ground crew. A log is kept of fuel consumed and any other weight changes that may occur during the tests.

Where feasible, communication is maintained between the airplane and phototheodolite crews by radio telephone.

EVALUATION OF DATA

Inasmuch as the two-phototheodolite method of take-off and landing measurement has been found to give generally more satisfactory results than the single phototheodolite system; only the former method will be considered directly in the ensuing discussion. In certain respects, however, the treatment of data obtained by either method would obviously be the same.

Evaluation of phototheodolite records.- The records obtained with the phototheodolites are usually read by means of a commercial-type motion-picture-film viewing or editing machine. A magnification factor of three diameters or greater is required in order to obtain the necessary accuracy of reading.

The films are first examined for identification of the frames in which the flash-bulb discharge appears (see fig. 3) in order to provide a common time reference for the two records. The time-counter changes are then noted, together with the corresponding frame numbers. Because the time at which a given counter change occurs can be determined only to within a certain interval (depending on whether the camera shutter is open or closed when the change occurs), this possible variation must be taken into

account in determining the relation between time and frame number. The method is indicated in figure 4, which illustrates the time plotting procedure for a typical case. In this figure, for convenience in plotting and greater accuracy in fairing, the greater part of the time variation has been eliminated by assuming an approximate straight line relation between time and frame number and plotting the difference t' between the actual time and the time obtained from this relation. The length of the small vertical marks denotes the time interval during which the counter change may have occurred. The time as defined by the faired curve is believed to be accurate to within ± 0.01 second.

The elevation and azimuth angles of the camera are read directly from the film. The corrections to these angles for sighting error is determined by measuring the offset of the image of some reference point on the airplane from the center of the frame by means of a suitably ruled transparent grid superimposed on the photographs. The reference point is usually a target painted on the side of the fuselage as near the center of gravity as possible. The azimuth and elevation angles for any given frame can be determined readily to within ± 2 minutes of arc; it is very important that such a degree of accuracy be realized if the data are to be used for the determination of velocities. Because the individual frames from the two phototheodolites are not synchronized, individual readings cannot be used directly but must be plotted against time and the faired values used.

The range of azimuth angles normally covered during a take-off or landing run is very large relative to the accuracy with which these angles can be determined so that it is inconvenient to plot the data directly to an appropriate scale and very difficult to fair the data, once plotted, with satisfactory accuracy. These difficulties are largely eliminated by determining an approximate simple relation between time and azimuth angle that will take care of all but one or two degrees of the angular variation. The residual angle can then be readily plotted and accurately faired. This procedure is illustrated in figure 5, in which time histories of the residual azimuth angles γ' and δ' of the two phototheodolites and the elvation angle β of phototheodolite 1 (see fig. 6) are plotted for the landing approach and flare of a medium bomber-type airplane. The actual azimuth angles for this case may be determined from the plotted data using the relations

$$\gamma = \gamma' - t$$

and

$$\delta = \delta' + 3.5t - 0.1(5 - t)^2$$

where t is time before the instant of first contact with the ground $(t = 0)$.

For determination of the attitude angle of the airplane, the angle between the image of a stripe painted on the side of the fuselage for this purpose (see fig. 3) and the edge of the frame is measured directly from the photographs.

<u>Determination of horizontal distance and velocity</u>.— The horizontal distance Δs traversed by the airplane between two points in the take-off or landing run or in a given time interval is determined from the relation

$$(\Delta s)^2 = D_2{}^2 - D_1{}^2 - 2D_1D_2 \cos(\delta_2 - \delta_1)$$

where D is the horizontal distance from one of the phototheodolites to the airplane and δ is the azimuth angle of the same phototheodolite; the subscripts 1 and 2 denote the two points between which the distance is to be determined or the beginning and end of the desired time interval. (See fig. 6.) The distance D is given by the relation

$$D = B \frac{\sin \gamma}{\sin (\gamma + \delta)}$$

where B is the distance between the two phototheodolites, and γ is the azimuth angle of the second phototheodolite. The azimuth angles δ and γ of the two phototheodolites are determined from faired time plots. (See fig. 5.)

The horizontal velocity is determined by evaluating Δs for a suitably small time interval Δt, say one second. Since $(\delta_2 - \delta_1) = \Delta\delta$ will be relatively small, $\cos \Delta\delta$ may be taken as $1 - \frac{1}{2}\left(\frac{\Delta\delta}{57.3}\right)^2$. The difference between D_2 and D_1 will generally be sufficiently small

that D_1D_2 can be replaced by D^2, where D is the value at a time intermediate between the times corresponding to D_1 and D_2 (that is, the value at the instant for which the velocity is being determined). If $D_2 - D_1$ is replaced by ΔD, equation (1) becomes,

$$(\Delta s)^2 = (\Delta D)^2 + D^2 \left(\frac{\Delta\delta}{57.3}\right)^2$$

The horizontal velocity is, of course,

$$V_h = \frac{\Delta s}{\Delta t}$$

<u>Determination of vertical distance and velocity</u>.— The vertical distance h of the reference point on the airplane from the horizontal plane passing through the phototheodolite is given by

$$h = D \tan \beta$$

where D is, as before, the distance between the phototheodolite and the airplane, and β is the faired value of elevation angle measured from the horizontal plane. In general, the results will be somewhat more accurate if D and β for the phototheodolite nearest the airplane are used.

The vertical velocity V_v may be determined from

$$V_v = \frac{dh}{dt} = \tan \beta \frac{dD}{dt} + D \sec^2 \beta \frac{d\beta}{dt}$$

Since β will not normally exceed 5°, the equation may be written

$$V_v = \left(\beta \frac{dD}{dt} + D \frac{d\beta}{dt}\right) \frac{1}{57.3}$$

or

$$V_v = \left(\beta \frac{\Delta D}{\Delta t} + D \frac{\Delta \beta}{\Delta t}\right) \frac{1}{57.3}$$

Determination of attitude angle.- The relation between the true attitude angle λ of the airplane and the apparent attitude angle ψ as measured on the photographs is

$$\tan \lambda = \frac{\tan \psi \sin \alpha + \sin \beta \cos \alpha}{\cos \beta}$$

where α is the angle between the optical axis of the phototheodolite and the airplane's course. (See fig. 6.) When the values of β and $\Delta\delta$ are small the equation may be written

$$\tan \lambda = \frac{D\Delta\delta \tan \psi + \beta \Delta D}{57.3 \Delta s}$$

where the sign of $\Delta\delta$ will always be considered positive and the sign of ΔD will be positive if D is increasing or negative if D is decreasing.

Example of evaluation of velocities.- The procedure of determining the horizontal and vertical velocities of the airplane from the phototheodolite data is demonstrated in table I for the case represented in figure 5, that is, the landing approach and flare of a medium bomber-type airplane.

The results of the computations of table I are plotted in figure 7 together with horizontal and vertical distances. The horizontal velocity is believed accurate to within ±2 miles per hour. Even better accuracy would have been realized had the disposition of the phototheodolites with respect to the airplane been more favorable, that is, if the angle δ had been smaller and the angle γ larger. (See table I.) The vertical velocity is believed to be correct to within ±1 foot per second except possibly where there is an abrupt change of acceleration such as is indicated by the hump in the vertical velocity curve at $t = 2$ seconds.

The corrected attitude angle of the airplane and the true airspeed are also plotted in figure 7. The trend of

the airspeed variation is shown to be reasonably close to that of the horizontal velocity. The crossing of the two curves is probably due to the fact that the wind during the test was light and gusty and varied considerably in direction.

CORRECTION OF LANDING AND TAKE-OFF DATA

In order that take-off and landing test results may have a general significance, it is desirable that the measured distances be corrected to standard atmospheric conditions (still air and standard density) and to a specific loading, power condition, and piloting procedure (defined by the airspeeds at the instant of take-off or of landing contact and at the instant of passing through the specified height level which constitutes the end of take-off or beginning of landing). A suggested method for correcting the test data is given below.

Correction of take-off ground run.- The relation between the measured take-off ground run distance and the several variables that affect it can be expressed by the equation

$$s_g = \frac{\left(\frac{V_1}{\sqrt{\sigma}} - V_{w_1}\right)^2}{2g\left(\frac{T_m}{W} - \frac{D_m}{W} - \mu\right)}$$

where

s_g the measured ground run distance

g the acceleration of gravity

V correct indicated airspeed

σ ratio of air density during tests to standard density

V_w wind speed

T_m mean value of effective thrust during ground run

D_m mean value of effective air resistance during ground run (including reduction of rolling resistance due to lift)

W gross weight of airplane at time of test

μ coefficient of rolling resistance of wheels

Subscript 1 denotes values at the instant of leaving the ground.

The equation for the corrected ground-run distance will be

$$s_{g_c} = \frac{{V_{1_o}}^2}{2g\left(\frac{T_{m_o}}{W_o} - \frac{D_{m_o}}{W_o} - \mu\right)}$$

where the subscript o denotes specified conditions. It has been shown in reference 2 that the mean value of thrust and resistance during take-off ground run is very nearly equivalent to the instantaneous values that would obtain at an airspeed $V_e = 0.7V_1 + 0.3V_{w_1}$. The relation between the mean effective resistance for the test conditions and for the specified conditions will be

$$D_{m_o} = D_m \frac{{V_{e_o}}^2}{{V_e}^2} = D_m \frac{\left(0.7V_{1_o}\right)^2}{\left(0.7V_1 + 0.3V_{w_1}\right)^2}$$

The equation for the corrected ground-run distance will then be

$$s_{g_c} = \frac{{V_{1_o}}^2}{2g\left[\frac{T_{m_o}}{W_o} - \frac{{V_{e_o}}^2}{{V_e}^2}\frac{W}{W_o}\left(\frac{T_m}{W} - \frac{1}{2gs_g}\left(\frac{V_1}{\sqrt{\sigma}} - V_{w_1}\right)^2 - \mu\right) - \mu\right]} \tag{1}$$

The values of T_m and T_{m_o} are calculated for the value of V_e, power, and air density corresponding to the test and the specified conditions, respectively, from propeller test data. A large amount of suitable full-scale propeller data has been made available in a number of NACA technical reports. The value of μ is about 0.02 for a smooth, paved runway and about 0.05 for a firm turf surface with short grass.

<u>Correction of take-off air run</u>.- For the air run the correction to no wind, including the effect of wind gradient, is given by the relation

$$s_{a_w} = \frac{s_a + \frac{1}{2} t_a \left(V_{w_1} + V_{w_2} \right)}{1 - \frac{(V_2 + V_1)(V_{w_2} - V_{w_1})}{2\sqrt{\sigma}\, gH}} \qquad (2)$$

where

s_{a_w} air-run distance corrected only for wind

s_a measured air-run distance

t_a measured time required to complete the air run

H specified height at end of the air run

Subscript 2 denotes values at the height H.

The relation between the air-run distance and the other influencing factors is expressed as

$$s_{a_w} = \frac{H + \frac{V_2^2 - V_1^2}{2\sigma g}}{\frac{T_a}{W} - \frac{D_a}{W}}$$

where T_a and D_a are the mean values of effective thrust and drag, respectively, during the air run. The corrected air-run distance can be represented by the equation

$$s_{a_c} = \frac{H + \frac{V_{2_0}^2 - V_{1_0}^2}{2g}}{\frac{T_{a_0}}{W_0} - \frac{D_{a_0}}{W_0}}$$

Since the speed during the air run will generally be fairly close to the speed at which the excess thrust is

a maximum, no serious error should be involved in the assumption that the excess thrust is not materially affected by moderate differences between the test speeds and the specified speeds. On the basis of this assumption the corrected air-run distance is given by

$$s_{a_c} = \frac{H + \dfrac{V_{2_0}{}^2 - V_{1_0}{}^2}{2g}}{\dfrac{T_{a_0}}{W_0} - \dfrac{W}{W_0}\left(\dfrac{T_a}{W} - \dfrac{H + \dfrac{V_2{}^2 - V_1{}^2}{2\sigma g}}{s_{a_w}}\right)} \tag{3}$$

where T_{a_0} and T_a are calculated from available propeller data, as before, for the specified and for the test engine power and air density; T_{a_0} and T_a are both calculated for the same indicated airspeed, say the specified take-off speed V_{1_0}.

<u>Correction of landing ground run</u>.- The deceleration during the landing ground run will ordinarily be determined principally by the degree of braking applied. Variations in braking cannot be corrected for (except by averaging the results of a number of tests) and there appears to be little point in attempting to correct for the relatively unimportant effects of such variations in the aerodynamic drag as may result from differences between the actual and specified or standard test conditions. The landing ground run is therefore corrected only for variations in the kinetic energy of the airplane at contact occasioned by differences in the speed of the airplane relative to the ground. The correction equation is, therefore, simply

$$s_{g_c} = s_g \frac{V_{1_0}{}^2}{\left(\dfrac{V_1}{\sqrt{\sigma}} - V_{w_1}\right)^2} \tag{4}$$

where the symbols are as previously defined for the take-off corrections.

<u>Correction of landing air run</u>.- For power-off landings, that is for landings where the engines are completely

throttled back before the landing air run begins, it is assumed that the effective lift-drag ratio during the air run will not be materially affected by moderate departures of the actual from the prescribed weight and landing speeds. When a technique is prescribed that involves the use of partial power during the final approach, the effective lift-drag ratio will probably vary considerably because of inadvertent variations in the application of power. Because taking account of such variations would be difficult, it is suggested that the measured air-run distances, for either power-on or power-off approach, be corrected only for wind and departures from the prescribed landing speeds; variations in the application of power during the air run would then have to be accounted for by averaging the corrected results of a number of tests. In accordance with the foregoing considerations the correction to the landing air run is

$$s_{a_c} = s_{a_W} \frac{H + \dfrac{{V_2}_0{}^2 - {V_1}_0{}^2}{2g}}{H + \dfrac{V_2{}^2 - V_1{}^2}{2\sigma g}} \tag{5}$$

where s_{a_W}, the air run distance corrected to no wind, is determined from equation (2) as for the take-off air run.

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TABLE I

CALCULATION OF VELOCITIES FROM PHOTOTHEODOLITE DATA

[Landing approach and flare; medium bomber; B = 2720 ft]

Time before contact, t (sec)	δ (deg) (1)	γ (deg) (1)	$\frac{D}{B} = \frac{\sin\gamma}{\sin(\gamma+\delta)}$	$\frac{\Delta D/\Delta t}{B}$ (2)	$\frac{\Delta\delta}{\Delta t}$ (deg/sec) (2)	$\left(\frac{\Delta s/\Delta t}{B}\right)^2 = \left(\frac{\Delta D}{B}\right)^2 + \left(\frac{D}{B}\right)^2\left(\frac{\Delta\delta/\Delta t}{57.3}\right)^2$	$V_h = \frac{B}{1.47}\,\frac{\Delta s/\Delta t}{B}$ (mph)	β (deg) (1)	$\frac{d\beta}{dt}$ (deg/sec)	$V_v = \frac{B}{57.3}\left(\frac{\Delta D/\Delta t}{B}\beta + \frac{D}{B}\,\frac{d\beta}{dt}\right)$ (fps)
-0.5	103.80	31.38	0.7383	------	----	-------	-----	----	-----	----
0	105.97	30.74	.7451	-0.0150	4.33	0.00341	108.2	-0.01	-0.010	-0.4
.5	108.13	30.12	.7533	-.0174	4.30	.00350	109.5	-.01	.008	.3
1.0	110.27	29.51	.7625	-.0195	4.26	.00361	111.3	-.01	.020	.7
1.5	112.39	28.91	.7728	-.0218	4.22	.00372	113.0	.01	-.065	-2.4
2.0	114.49	28.33	.7843	-.0243	4.15	.00381	114.4	.06	-.110	-4.2
2.5	116.54	27.75	.7771	-.0266	4.07	.00393	116.1	.09	-.018	-.7
3.0	118.56	27.19	.8109	-.0292	4.00	.00404	117.8	.09	-.004	-.3
3.5	120.54	26.65	.8263	-.0320	3.89	.00418	119.8	.09	-.032	-1.3
4.0	122.45	26.11	.8429	-.0343	3.77	.00428	121.2	.12	-.090	-3.8
4.5	124.31	25.60	.8606	-.0366	3.67	.00438	122.6	.18	-.156	-6.7
5.0	126.12	25.09	.8795	-.0387	3.55	.00447	123.9	.27	-.198	-8.8
5.5	127.86	24.59	.8993	-.0407	3.41	.00454	124.8	.38	-.246	-11.2
6.0	129.53	24.10	.9202	-.0427	3.31	.00465	126.3	.51	-.277	-13.1
6.5	131.17	23.63	.9420	-.0444	3.23	.00480	128.3	.65	-.308	-15.1
7.0	132.76	23.17	.9646	-.0458	3.11	.00486	129.1	.82	-.336	-17.2
7.5	134.28	22.72	.9878	-.0475	2.97	.00488	129.5	.99	-.370	-19.7
8.0	135.73	22.29	1.0121	-.0490	2.83	.00489	129.5	1.18	-.396	-21.9
8.5	137.11	21.87	1.0368	-.0503	2.70	.00492	129.8	1.39	-.405	-23.1
9.0	138.43	21.46	1.0624	-.0519	2.58	.00498	130.8	1.58	-.360	-22.0
9.5	139.69	21.06	1.0887	-.0531	2.45	.00499	130.9	1.75	-.340	-21.9
10.0	140.88	20.68	1.1155	-.0540	2.34	.00500	131.0	1.92	-.324	-22.0
10.5	142.03	20.30	1.1427	-.0550	2.25	.00503	131.4	2.08	-.314	-22.4
11.0	143.13	19.94	1.1705	-.0557	2.16	.00506	131.7	2.24	-.318	-23.6
11.5	144.19	19.58	1.1984	------	----	-------	-----	----	-----	----

[1] From faired curves of figure 5.

[2] Increments for one-second intervals.

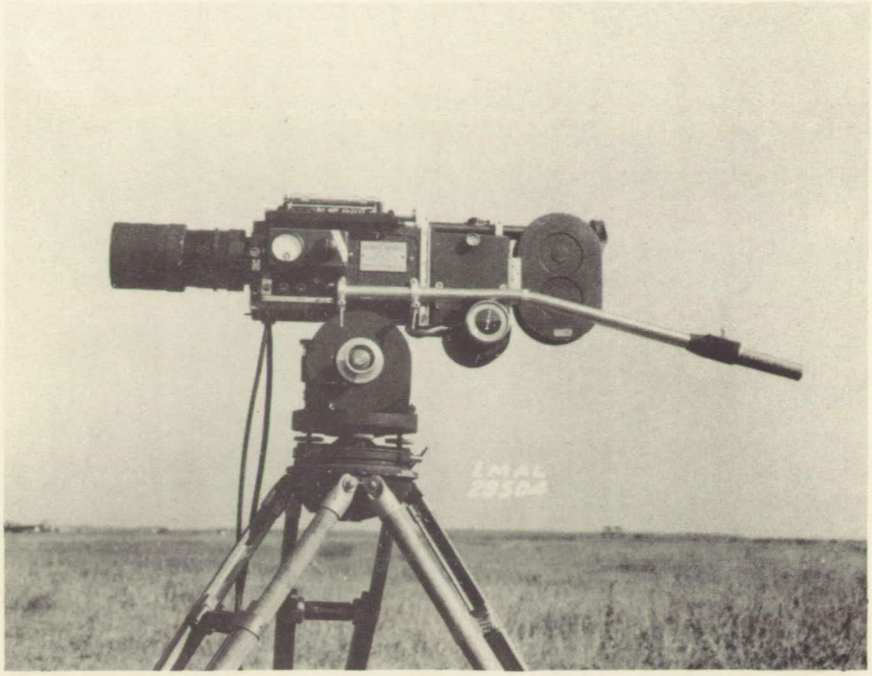


Figure 1.- The NACA phototheodolite.

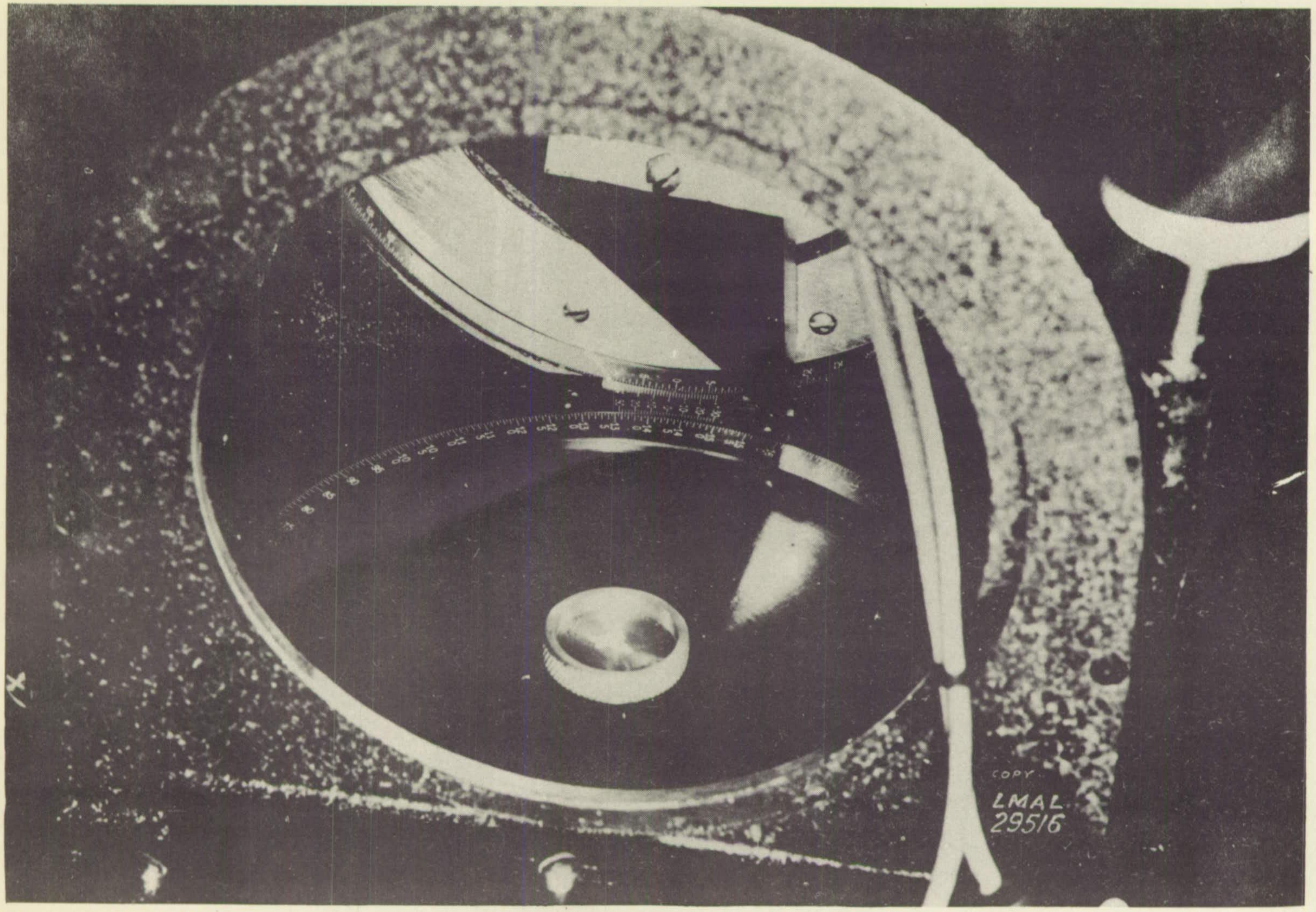


Figure 2.- View of interior of base of NACA phototheodolite showing azimuth- and elevation-angle dials and vernier.

Figure 3.- Section of record obtained with NACA phototheodolite. Note flash of photographic flash bulb in nose of airplane in two lower frames.

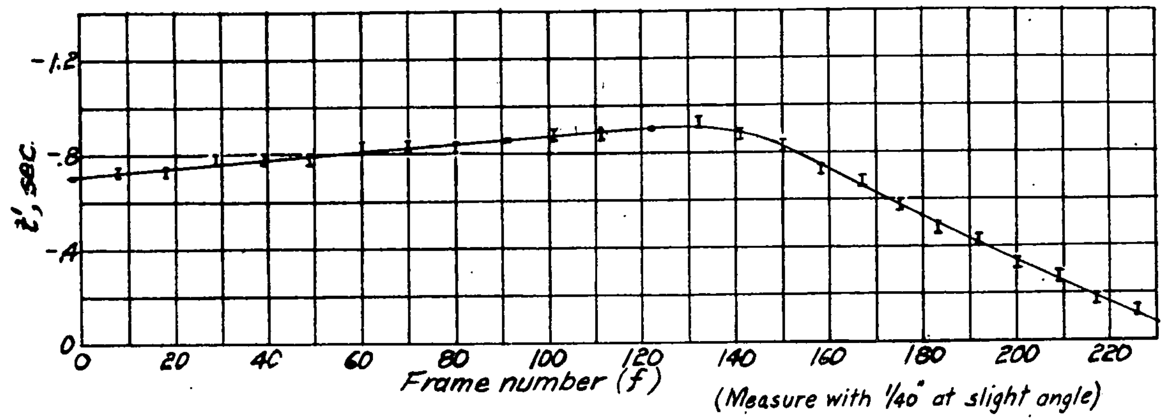


Figure 4 - Illustration of method of determining relation between time and frame number. (Time before contact = t' + 0.9 + .05f.)

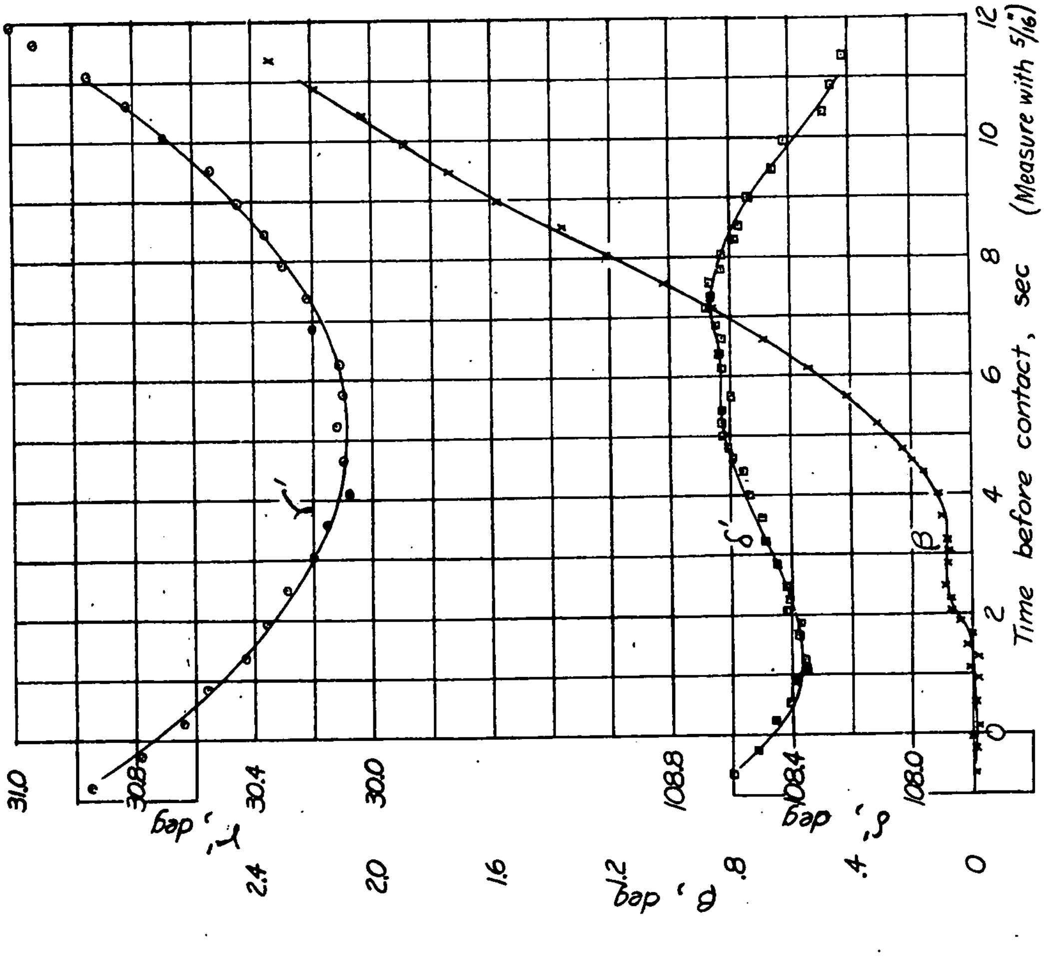


Figure 5.- Plot of azimuth and elevation angles determined from phototheodolite records of landing approach and flare of a medium bomber-type airplane.

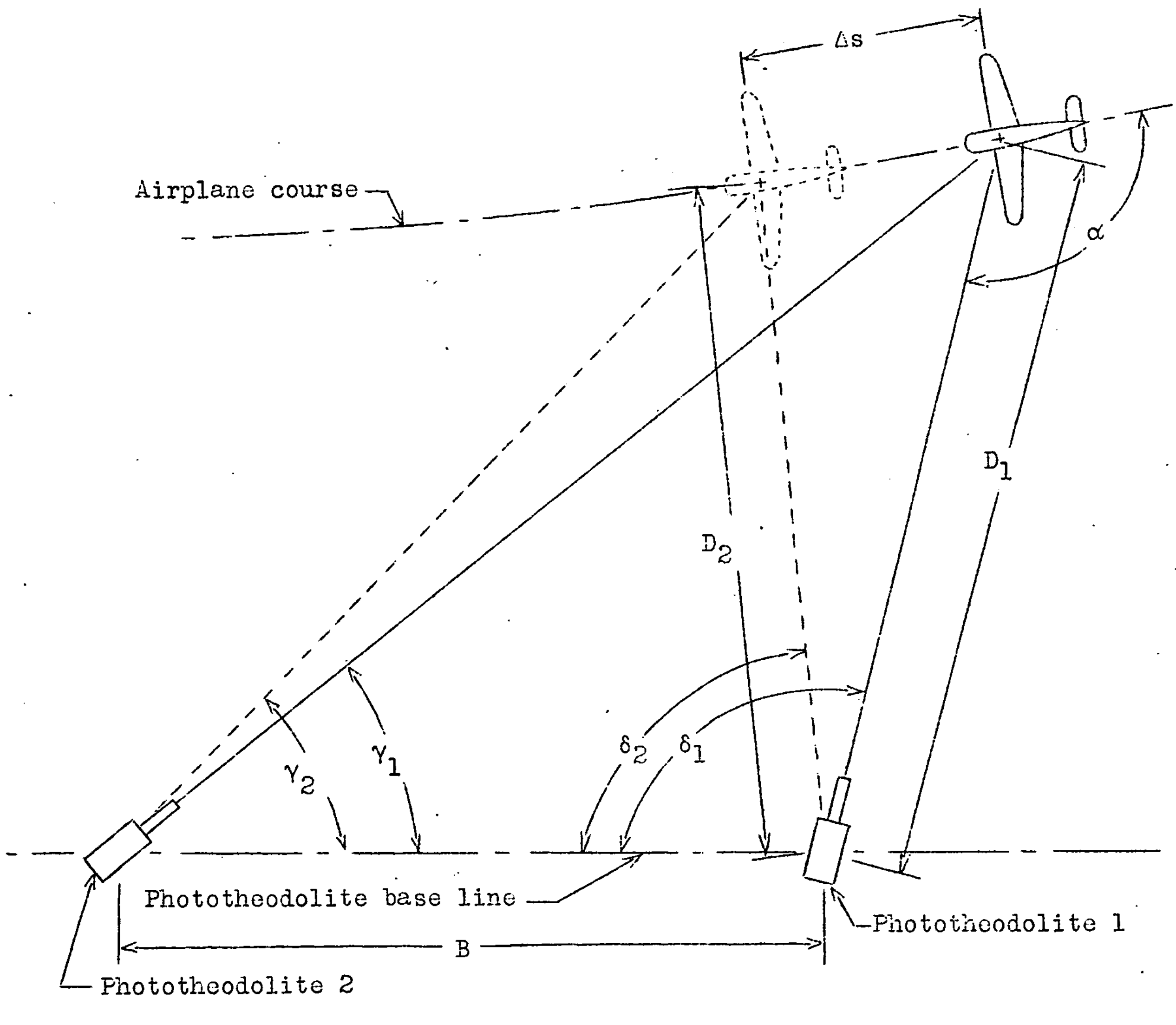
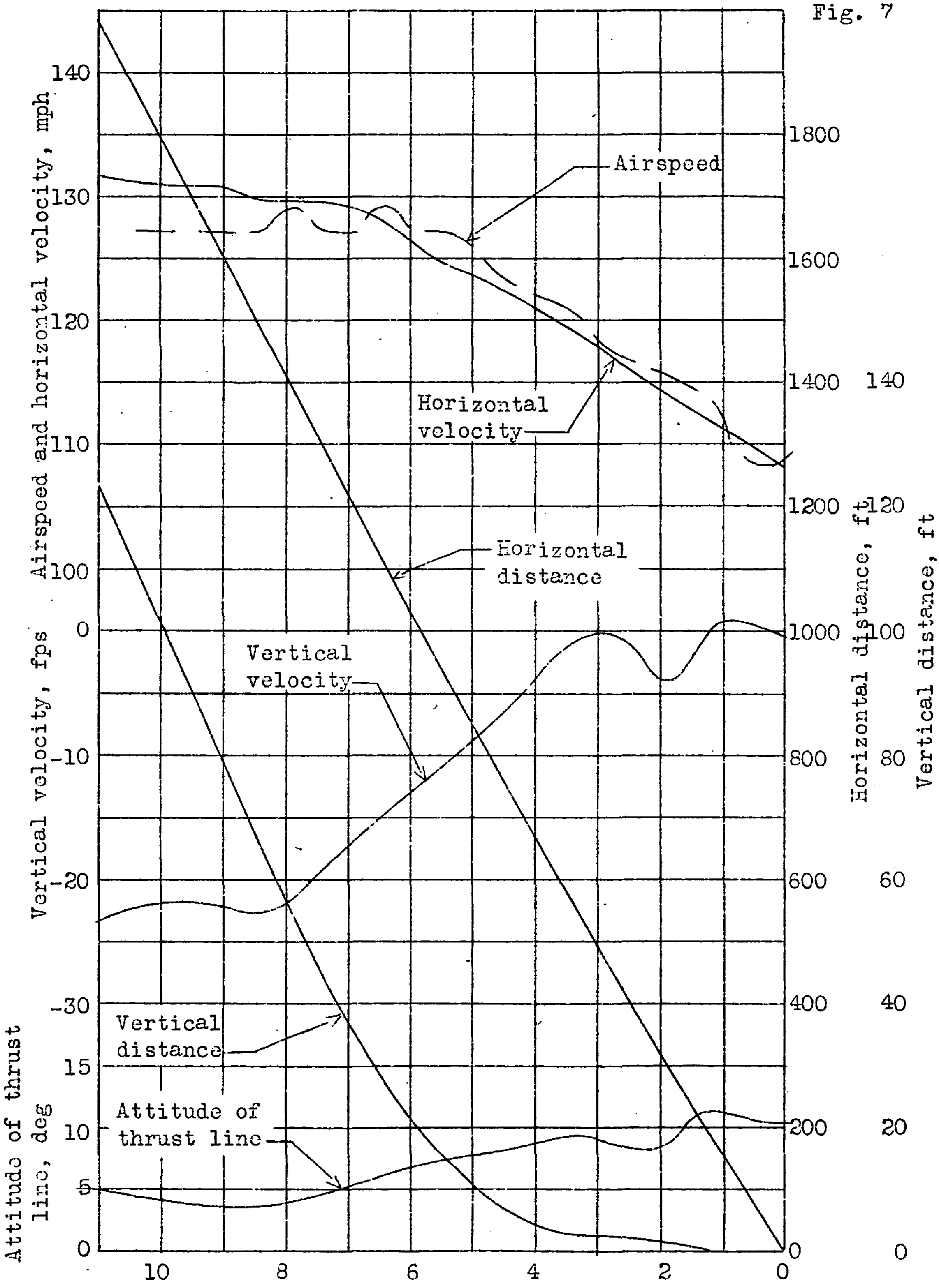


Figure 6.- Diagram illustrating method of evaluating phototheodolite data.



(Measure with 1/50")

Figure 7.- Plot of data evaluated from records of landing approach and flare of a medium bomber-type airplane.